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ENGINEERING PROGRESS REPORT NO. 19

ON

DEVELOPMENT PROGRAM FOR AN AUTOMATIC PILOT FOR HIGH PERFORMANCE AIRCRAFT

GET-2257-11

Period covered
7-24-52 - 9-24-52

Submitted
November 5, 1952

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FOR

UNITED STATES AIR FORCE
AIR MATERIEL COMMAND
WRIGHT - PATTERSON FIELD

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TABLE OF CONTENTS

SECTION I

PURPOSE

The purpose of this project is: to study, design, and build a flyable breadboard model of an automatic pilot which will provide stable, positive control of bombardment, transport, cargo and fighter-type aircraft from landing speeds thru the sonic range and up to speeds anticipated for aircraft that will be flying by 1956.

SECTION II

GENERAL FACTUAL DATA

A. A total of 93261 engineering and drafting man hours have been devoted to this project to date.

B. Development and construction of components suitable for flight testing the fighter type and bomber type autopilots will be complete by 31 January 1953.

C. No manufacturing difficulties were encountered during this period.

D. The assistance of a Project Engineer is required to (1) arrange for a suitable flight test program and (2) resolve the matter of additional funds to provide engineering service for the flight test program.

E. No patent dockets were filed during this period.

F. Field trips made during this period:

8 Oct. 1952	WADC, Dayton Office

SECTION III

SYSTEM DEVELOPMENT

A. BOMBER AUTOPILOT

1. General

System development on the bomber autopilot during this period has been confined to studying possible applications of the system to several bomber aircraft. The primary difference in the various applications is the type of control surface servo system chosen.

Evaluation of the requirements of the bomber installations indicates that the basic servo system incorporating a series damper servo actuator driving a manual valve and piston actuator plus an autopilot servo actuator connected in parallel with the power actuation control system is the best system available at present.

A summary of all of the ultimate servo systems proposed and studied during this program together with recommendations for further development and/or flight test evaluation will be presented in Progress Report No. 20.

2. System Analysis

A short study was made during this period to compare the yaw damping and turn coordination achieved with a yaw vane (or pendulum) and rate gyro system with that achieved by a linear accelerometer (mounted forward of the c.g.),

The characteristics of a high performance bomber were

simulated in this analysis; and a five degree heading correction was used as the basis for comparing the two systems.

a. Linear Accelerometer (forward of c.g.) Damping and Coordination System.

Figure 1 (a) is a stability block diagram of the system analyzed. Figure 1 (b) shows the damping characteristics of the airplane alone; and Figure 1 (c) illustrates the airplane autopilot combination.

In this system it is important to note that: (1) the rudder position feedback (K_F, in the rudder channel) is zero, so the control surface rate - rather than position - is proportional to acceleration; and (2) roll rate feedback is used in the rudder channel to eliminate the adverse yaw tendency on entering turns.

b. Yaw Vane + Yaw Rate Gyro System

Figure 2 (a) is the stability block diagram of this system. Here again, roll rate gyro feedback is used, although in this case similar results may be obtained by tilting the sensitive axis of the yaw rate gyro to sense roll rates.

Figure 2 (b) shows the transient response of this system. The damping is somewhat better than the linear accelerometer system.

Further work will be done during the next period to determine the practicality and flexibility of the linear accelerometer system through flight tests on the G. E. B-25 airplane.

B. FIGHTER AUTOPILOT

1. F-94 Program

Ground check-out of the fighter autopilot system in the F-94 has started. Delays encountered during this period were due to several factors: (1) re-packaging of magnetic amplifiers; (2) B-25 flight test evaluation of the longitudinal control system; and (3) modification of the elevator channel of the autopilot.

The elevator channel modification was made in order to evaluate two different longitudinal control systems during the F-94 flight test program. The first system incorporates the altitude - altitude rate sensor with no pitch attitude reference. This is the No. 1 system described in Progress Report No. 15.

The second method of longitudinal control which can be tested on the F-94 uses a Kearfott Vertical Gyro as the pitch attitude reference. This is the No. 2 System described in Progress Report No. 15.

The addition of a "Transfer Relay" to the junction box of the fighter autopilot plus a switch on the pot extender box located in the radar operator's compartment of the F-94 now makes it possible to transfer from the No. 1 to the No. 2 system while in flight. In this way performance comparisons of two different longitudinal control systems can be made easily.

Comparison of two types of lateral control can also be

made in flight. A "yaw vane - pendulum" switch on the potentiometer Extender Box is used to select the coordination control reference.

2. Fighter Autopilot System Diagram

Figure 9 is a sketch of the fighter autopilot system now installed in the F-94.

The throttle channel components (amplifier, actuator, control chassis and airspeed sensor) are shown, but their interconnection in the junction box is not indicated since this wiring is not now in the F-94.

Delivery of the airspeed sensor during the next period will accelerate bench tests of the throttle channel. As soon as these tests are complete the necessary wiring additions will be made to the F-94 installation.

During the next period an "Elementary System Diagram" will be compiled from existing drawings. This diagram will include the rudder, aileron, elevator, and throttle channel signal circuits and the system relaying information. The "System Interconnection Diagram" shown in Figure 9 can be used for component and cabling trouble shooting, while the "Elementary System diagram" will be most useful in system trouble shooting.

3. System Analysis - Glide Path Response

The glide slope loop of the navigational coupler was put on the Goodyear computer to compare its performance with a conventional autopilot and its performance with a pitch channel using

altitude rate stabilization.

Figures 7 (a) and 7 (b) show the long and close range responses to a step error of glide slope when a conventional autopilot (with vertical gyro) is used.

Figure 7 (c) and 7 (d) illustrate transient responses when the altitude rate stabilization is used in the pitch channel.

The airplane simulated was the B-25. The symbols on the brush recordings are defined as:

θ - The Pitch Angle

$p\theta$ - Rate of Pitch

δ_e - Elevator Deflection

Δx - Departure from Beam Center Line

ph - Rate of change of Altitude (Ft/sec)

The steady state gain of the coupler was 125 a-c volts out for 1 d-c volt of cross pointer signal.

The output of the glide slope receiver was limited to give a maximum of $\pm 5^{\circ}$ of pitch for the conventional autopilot and $\pm$ 13 ft/sec. from the mean rate of descent for the altitude rate channel.

In the altitude rate type of pitch control it was found necessary to greatly increase the pitch rate gyro gradient over that needed for airplane stability to give smooth control along the glide slope beam.

4. B-25 Flight Tests

a. Fighter Autopilot Longitudinal Control

Longitudinal control without the vertical gyro has been flight tested again on the General Electric B-25. The instability in the system reported in Progress Report No. 18 was due to overloading of the altitude rate pickoff in the Avion Unit. Proper impedance matching corrected this difficulty and several successful flight tests have been run. It is felt that the system has been proven and no further tests are planned until the F-94 flight tests.

Some difficulty with the Avion Altitude Unit was experienced in the last flight test. Examination of the unit in the laboratory showed that the tube sockets were not making contact and one of the motor tachometer windings was intermittent. This trouble has been corrected by Avion.

The above system was demonstrated to the WADC project engineer, and flight recordings were made during the final flight test.

In general, altitude - altitude rate stabilization does not provide as tight longitudinal control of the airplane as pitch attitude control through vertical gyro feedback, however, for relief autopilot operation in a fighter autopilot, its performance is considered satisfactory.

b. Force Switch Maneuvering

The principles of force switch maneuvering originally

described in Progress Report No. 15 were flight tested in the B-25 and a demonstration flight was made for the WADC project engineer.

Figure 3 is a photograph of the installation made in the G. E. B-25. For ease of installation and minimization of modification to the existing airplane flight control system, a separate wheel was mounted on the co-pilot's control wheel.

The two wheels were connected to each other through a helical spring enclosed in the cylindrical housing between the two wheel centers. Rotation of the additional wheel was opposed by torsion load of the spring, and fore and aft motion of the wheel was opposed by the compression and tension loads of the same spring.

Application of forces on the control wheel in excess of 10 - 15 lbs. actuated either or both the aileron channel and elevator channel force switches (detent switches located within the spring housing) depending upon how the force was applied.

Actuation of the force switches disengaged the respective autopilot channel, thereby returning the autopilot to the synchronizing mode of operation in that particular channel.

Three methods of operation were tested:

(1) Force switch disengagement of the autopilot upon entering maneuvers with manual re-engagement (through microswitch on wheel shown in figure 3) when the desired attitude is obtained.

(2) Force switch disengagement of the autopilot upon application of force to control wheel with automatic re-engagement of the autopilot (synchronized with the desired attitude) upon removal of this force.

(3) The same as (2) except for the addition of a one to three second time delay in re-engagement following removal of force.

Flight tests in the B-25 proved all three methods were satisfactory, and that the #2 method was perhaps the most desirable since the manual operations were minimized.

It is proposed that the force switch maneuvering system be investigated further during the F-94 flight test program at WADC or during the bomber autopilot flight test program.

SECTION IV

COMPONENT DEVELOPMENT

A. BOMBER REFERENCE SYSTEM

Cause of erratic day to day drift rates in the integrating rate gyros is still under investigation. Tests have shown that balancing of the drift-producing torque is possible by applying a counter-balancing torque through the torque motor normally used for slaving the gyros to the vertical.

At present this balance adjustment is made by manually setting in a bias voltage in the torque motor control circuit.

To eliminate the necessity for this manual adjustment, a breadboard integrating system is now being evaluated. The output of the erecting pendulums is integrated slowly and used to drive the bias adjustment potentiometer which in turn, through the torque motor in the integrating rate gyro, supplies the necessary torque required to offset the drift - producing torque.

B. MAGNETIC AMPLIFIERS

1. Amplifier for Hydraulic Servo

The flight-test sub-assembly of the magnetic amplifier developed for the hydraulic servo system was tested during this period. A photograph of this unit is shown in Progress Report No. 18.

This sub-assembly uses all selenium rectifiers. Toroidal reactors are used and in the output stage ultimately will be used

throughout. This will result in additional savings of weight and space.

Open loop response of the amplifier alone is shown in figure 5a. This shows the attenuation of the solenoid current as a function of frequency. The response of the two-stage valve alone is shown in figure 5b. This indicates a 6 decibel break at 40 radians, and this break was found to be caused by the two stage valve. When the loop was closed, using a selsyn generator as the input signal, the resultant response was as shown in figure 6.

The limiting item in this loop, as seen from the above curves, is the two stage valve. Response of this valve can be improved by either increasing the control oil flow through the capillaries or decreasing the diameter of the second stage valve stem. Increasing control oil flow results in higher stand-by power. Decreasing the valve stem diameter results in less power output. This is caused by a lower capacity of the valve. Both of these methods have been tried on other projects with a resulting frequency response improvement of two or three times that of the present valve.

An investigation is being made at the present time to determine if the present response is satisfactory, or if either or both of the above remedies are acceptable for improving the response of the two stage valve.

2. Basic Servo Amplifier Development

While work continues on development of the all-toroid, all selenium type amplifier, present effort is being concentrated on improving the frequency response.

3. Flight Test Amplifier Re-Packaging

As mentioned in Section III B1, the magnetic amplifiers for the F-94 program have been re-packaged. When the sub-assemblies were assembled into the control amplifier, heat from the thyratrons raised the temperature beyond the limit of the diodes. The solution was to place the thyratrons and other heating elements on a separate chassis. Figure 4 shows this thyratron chassis, which includes the thyratrons, filament transformers, and tachometer voltage dropping resistors for all three control surface channels. In addition this chassis includes a blower for cooling and precision resistors for remote measurement of motor current.

C. MISCELLANEOUS COMPONENTS

1. Angular Accelerometer

The angular accelerometer described in Progress Report No. 18 is now in the final stages of assembly. The servo amplifier has been designed and a breadboard model built.

Tests of this unit will be completed during the next period.

2. Bomber Throttle Servo Actuator

A four-pulley throttle servo actuator suitable for installation and flight tests in bomber aircraft has been completed and is ready for bench tests as a part of the longitudinal control system.

Figure 8 is a photograph of this unit.

SECTION V

PLANS FOR NEXT PERIOD

A. BOMBER AUTOPILOT

1. Continue construction of flight test components. Make component and system modifications necessary to evaluate the autopilot in a B-47 rather than a B-45.

2. Prepare a proposal for a bomber autopilot flight test program to be conducted in a B-47 at WADC.

3. Flight test bomber system features, such as: (a) altitude error integration; and (b) lateral accelerometer damping and co-ordination control in the General Electric B-25.

B. FIGHTER AUTOPILOT

1. Conduct flight tests in F-94 at Schenectady.

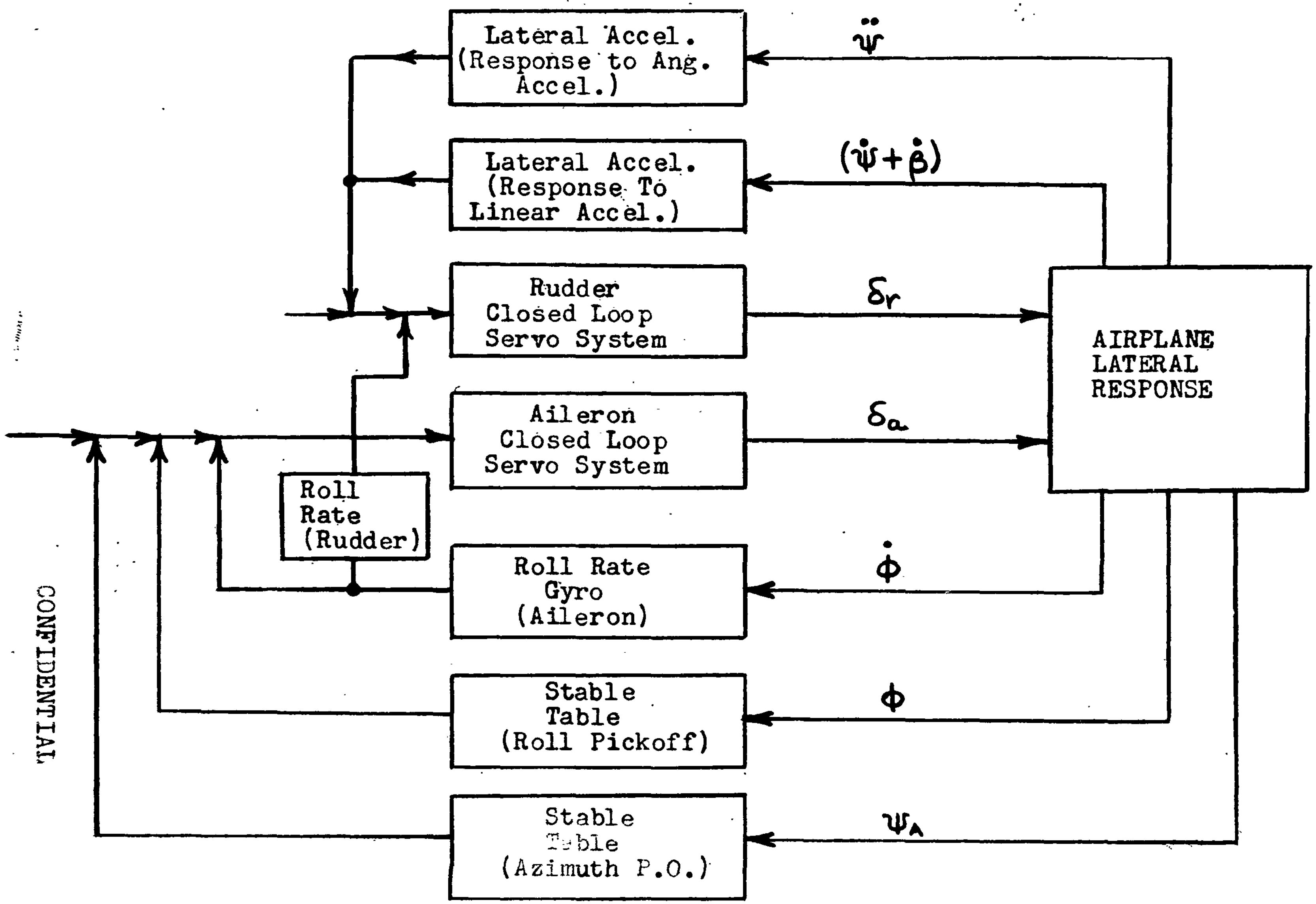
2. Prepare a proposal for a developmental flight test program in the F-94 at WADC.

3. Bench test Avion airspeed sensor

C. GENERAL

1. Flight test navigational coupler in B-25

2. Continue development of magnetic amplifiers.



LATERAL CONTROL CONFIGURATION

FIGURE 1 (a)

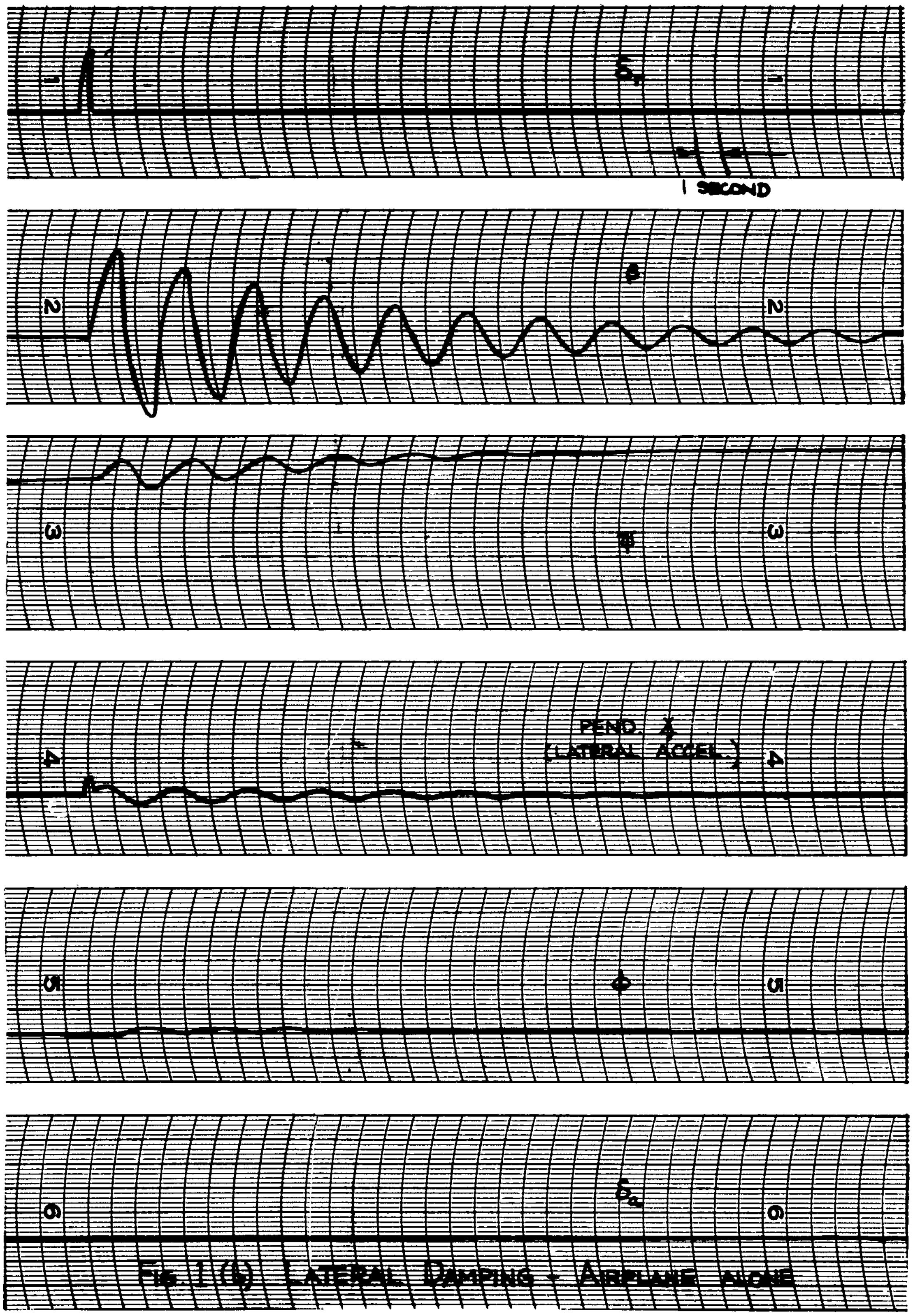


Fig. 1 (b) Lateral Damping – Airplane alone

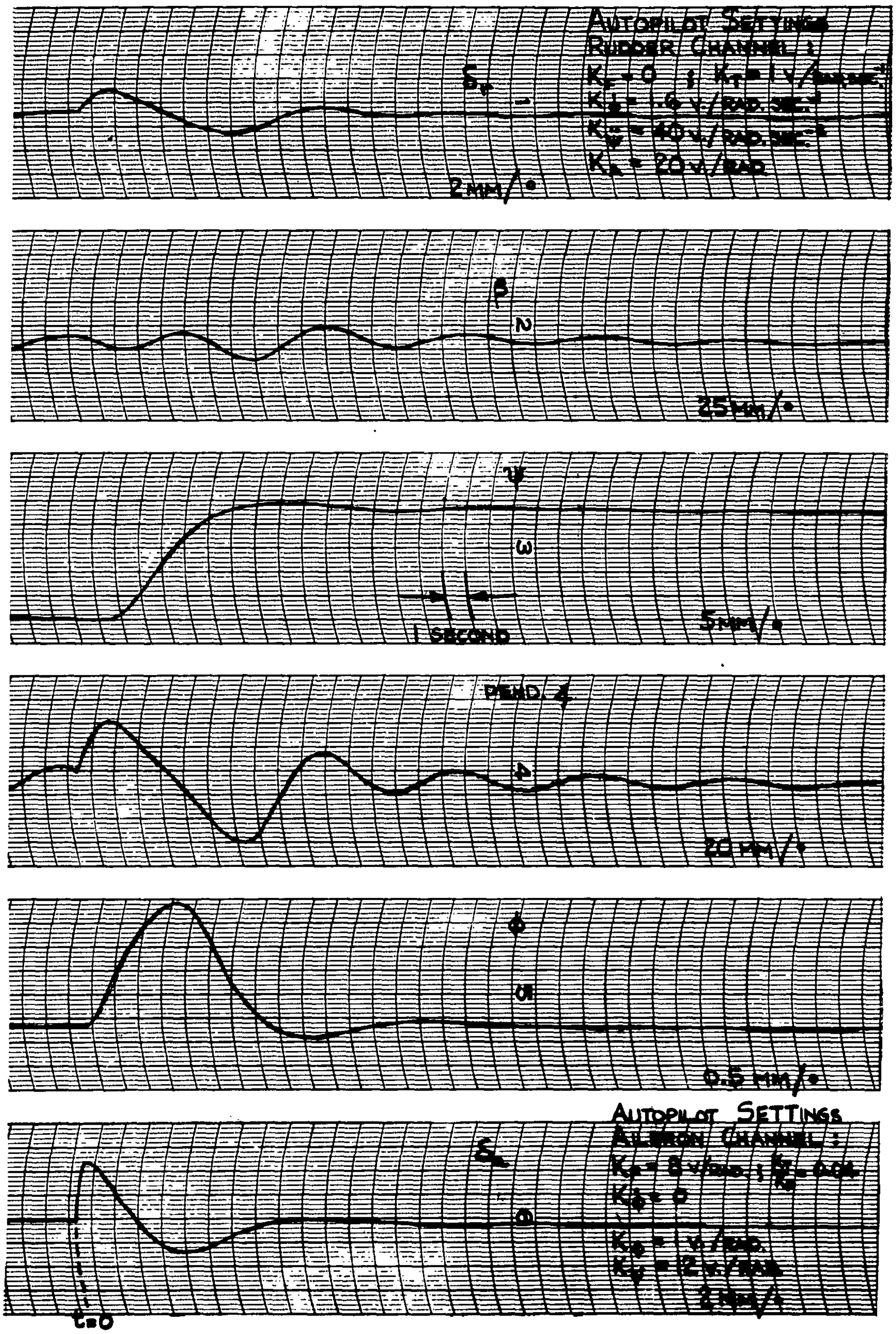


Figure 1(c). Transient Heading Response – Accelerometer System

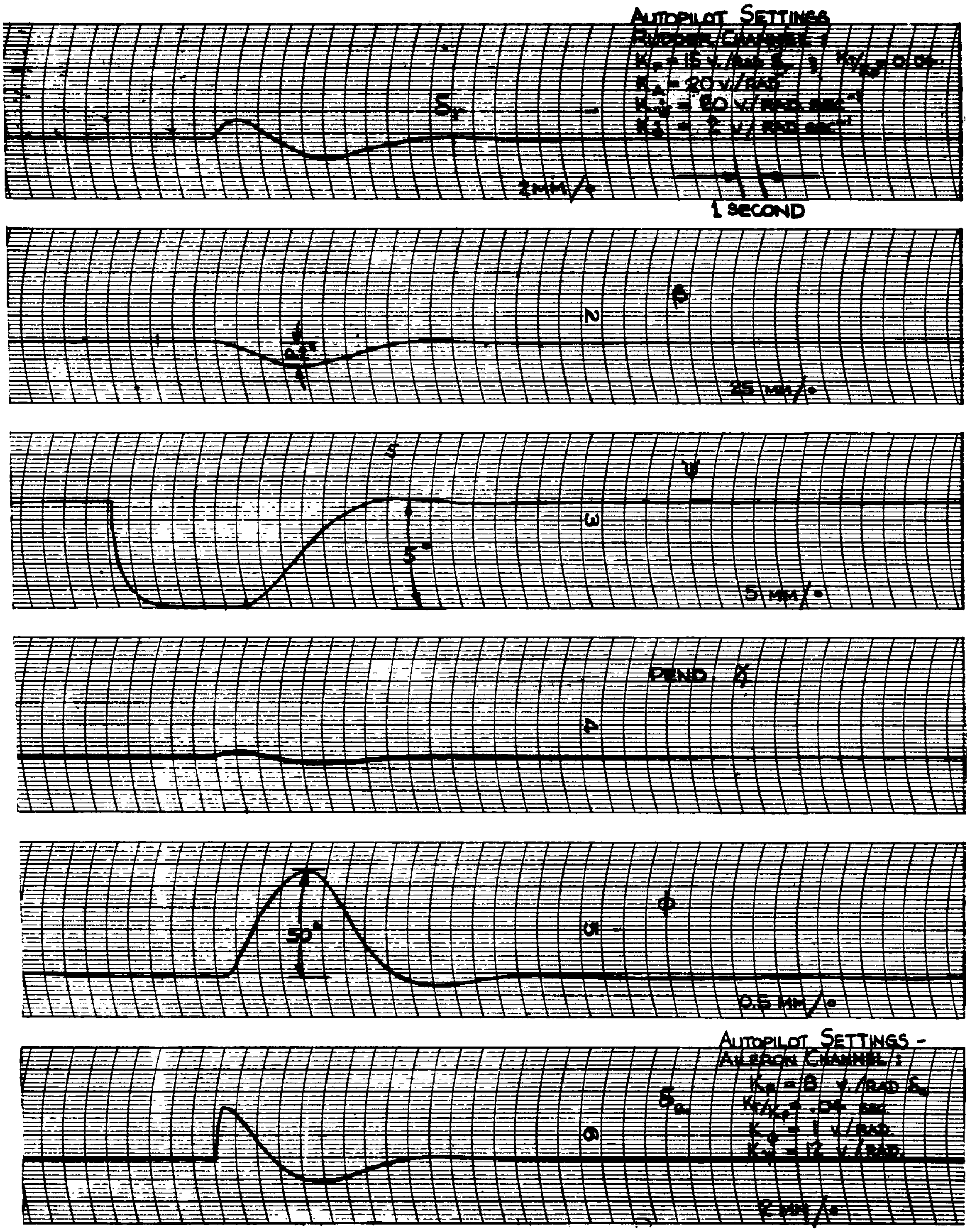


Figure 2(b). Transient Heading Response – Yaw Vane and Yaw Rate System

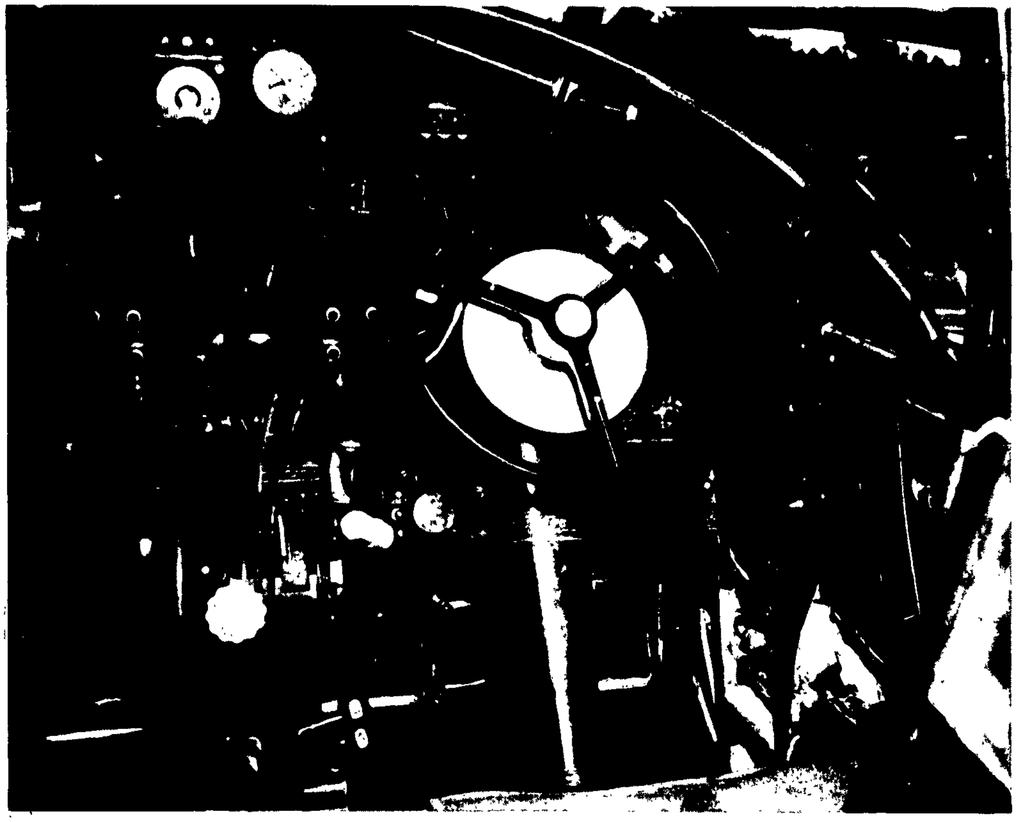


Figure 3. Force Switch Wheel Installation

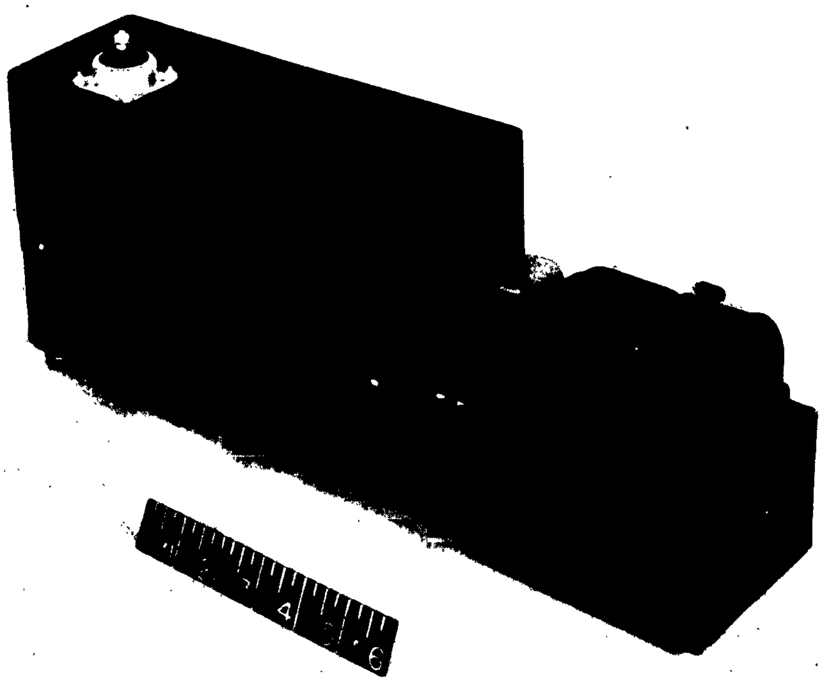


Figure 4. Thyratron Chassis

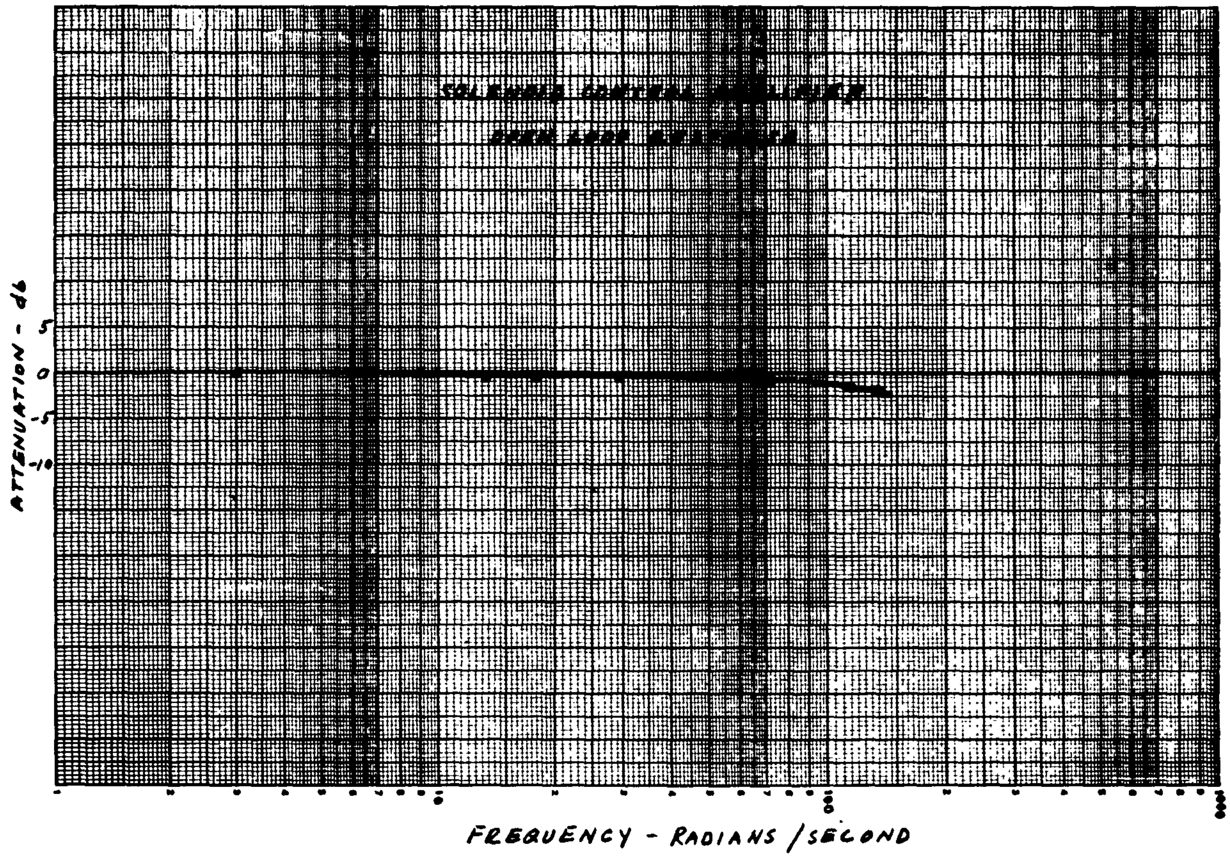


Figure 5(a). Solenoid Control Amplifier, Open Loop Response

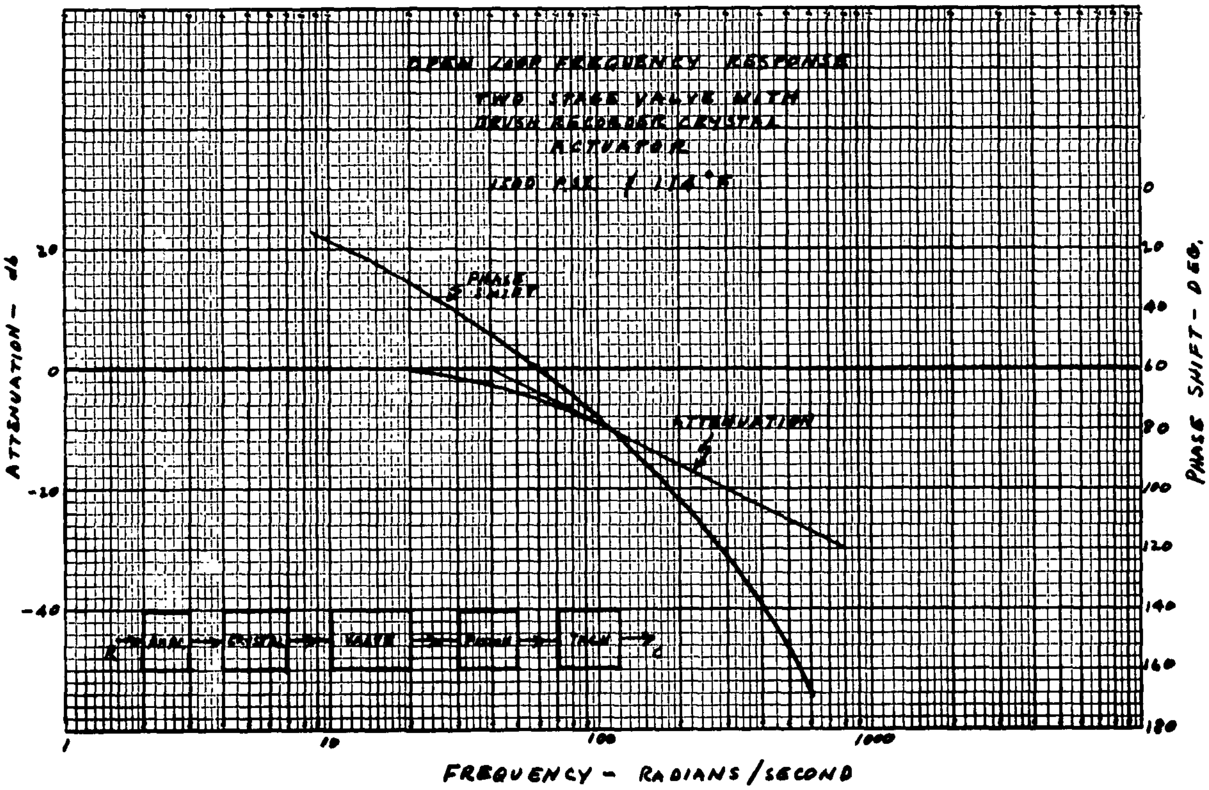


Figure 5(b). Open Loop Frequency Response

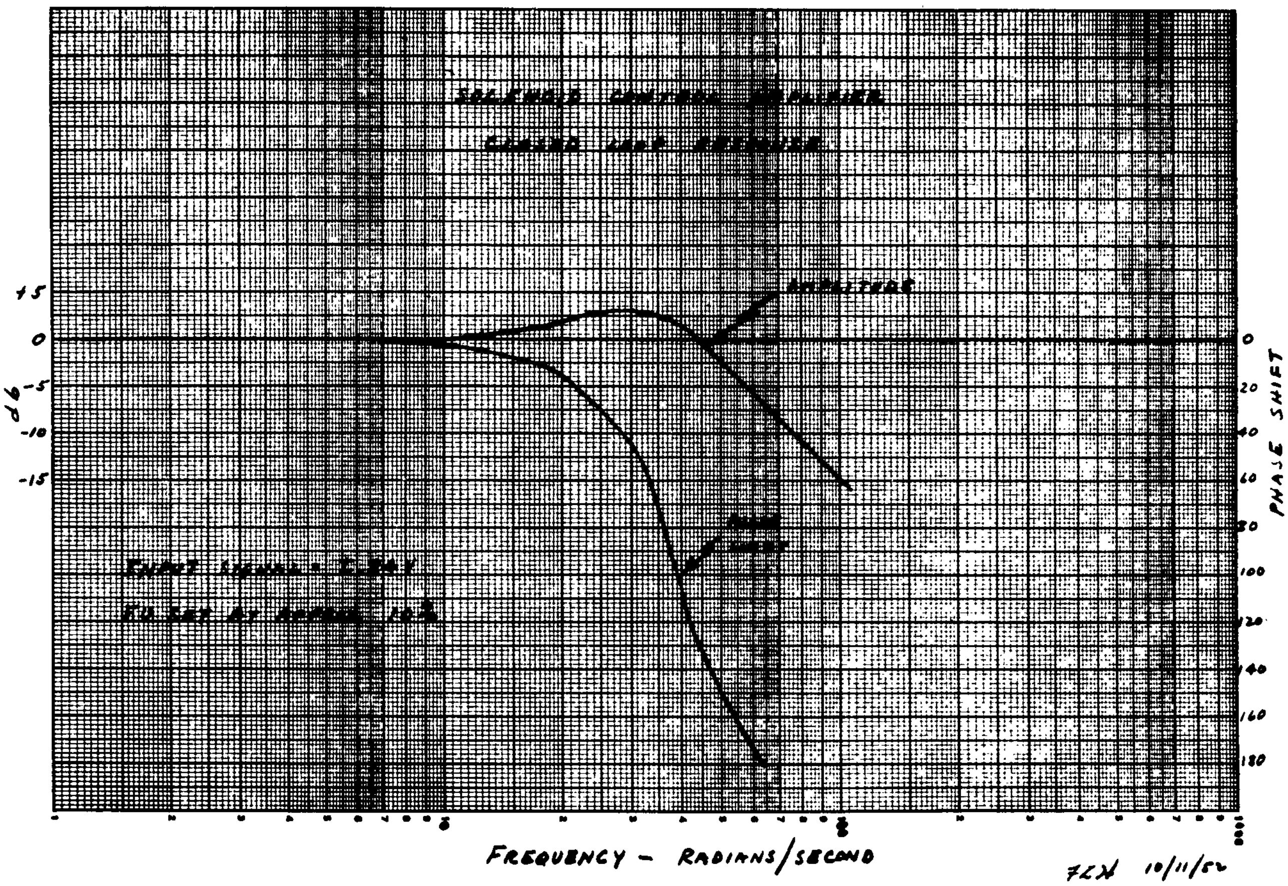


Figure 6. Solenoid Control Amplifier, Closed Loop Response

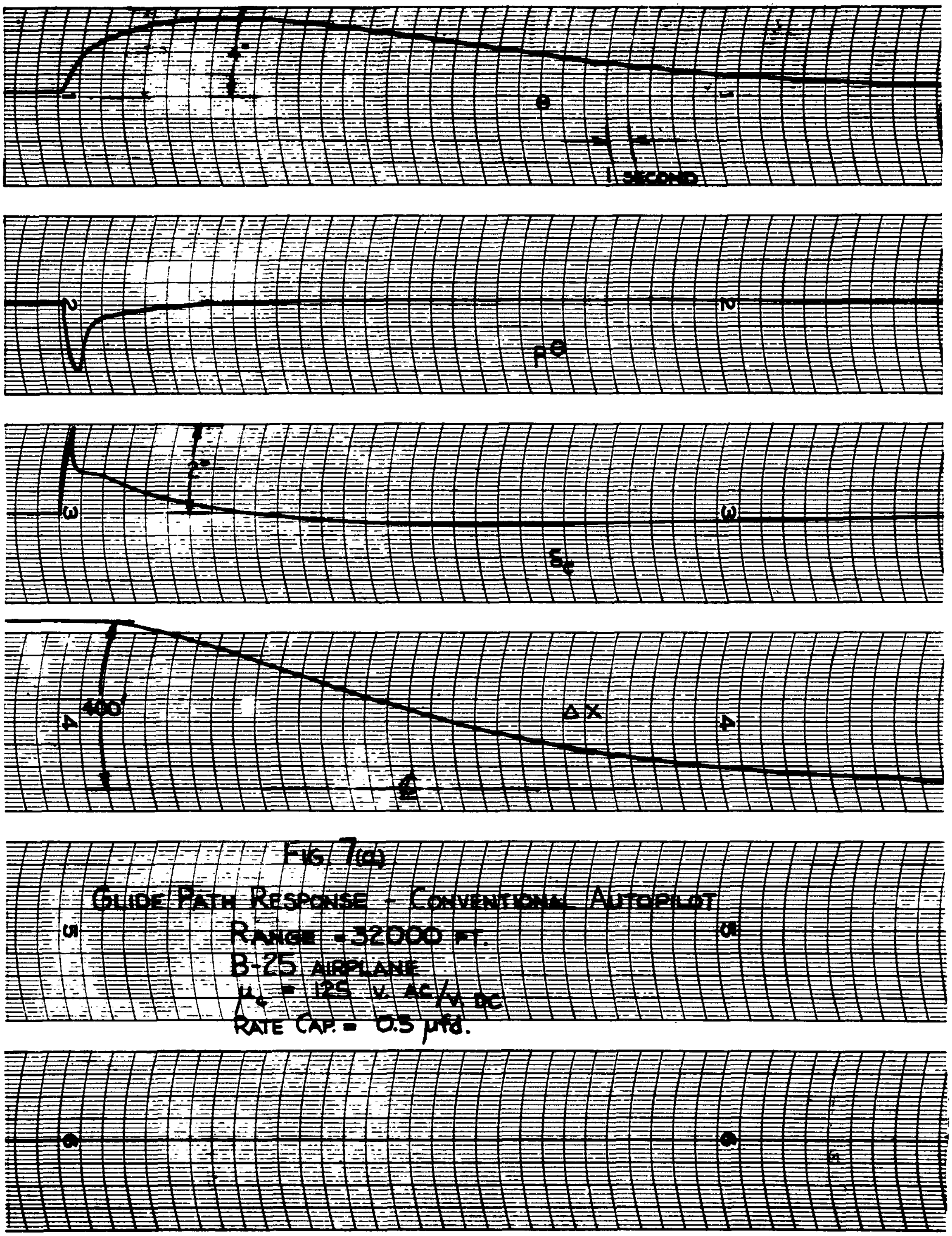


FIG. 7(a)
GLIDE PATH RESPONSE - CONVENTIONAL AUTOPILOT
RANGE = 32000 FT.
B-25 AIRPLANE
μ_c = 125 V. AC/V. DC
RATE CAP. = 0.5 μfd.

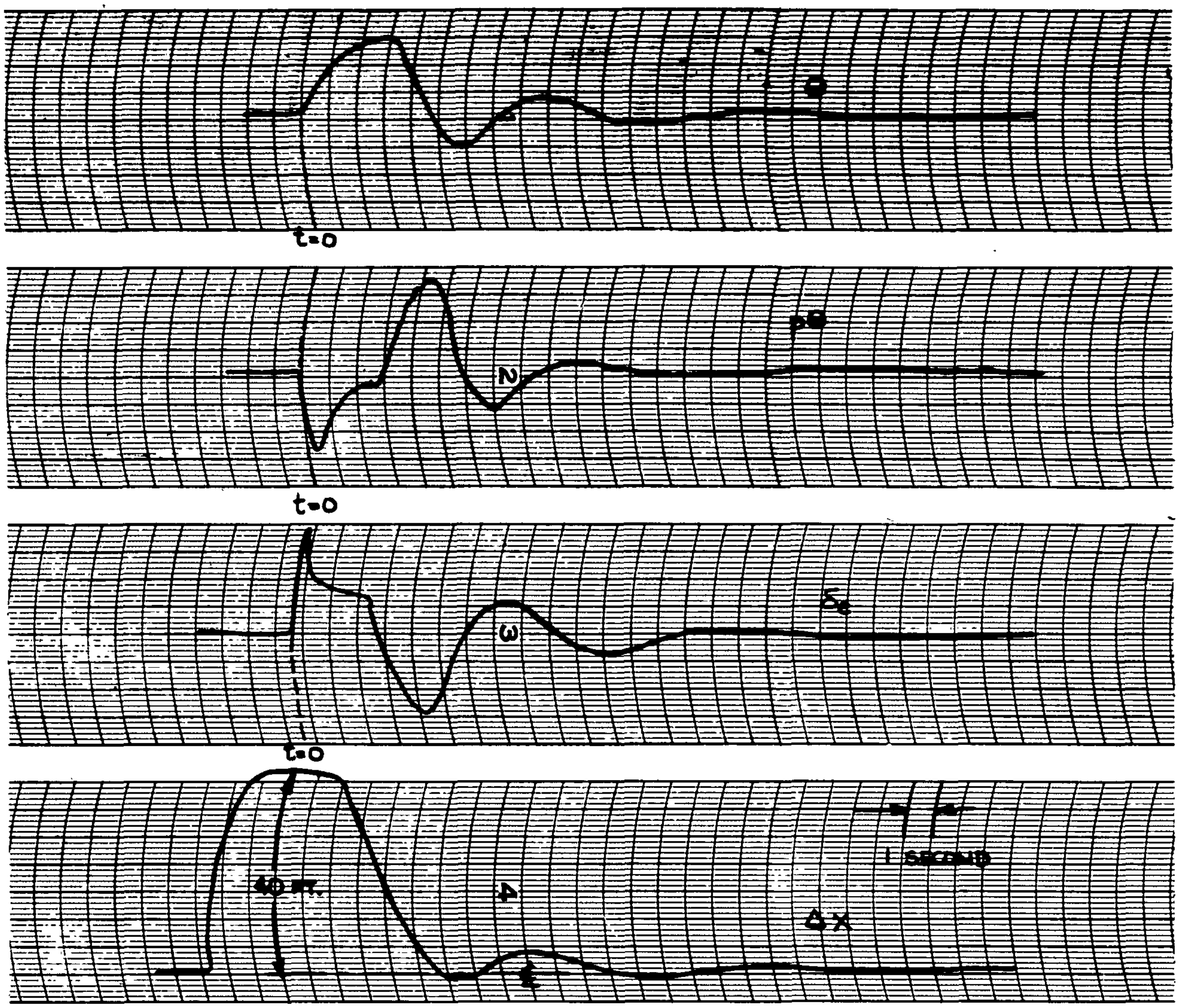
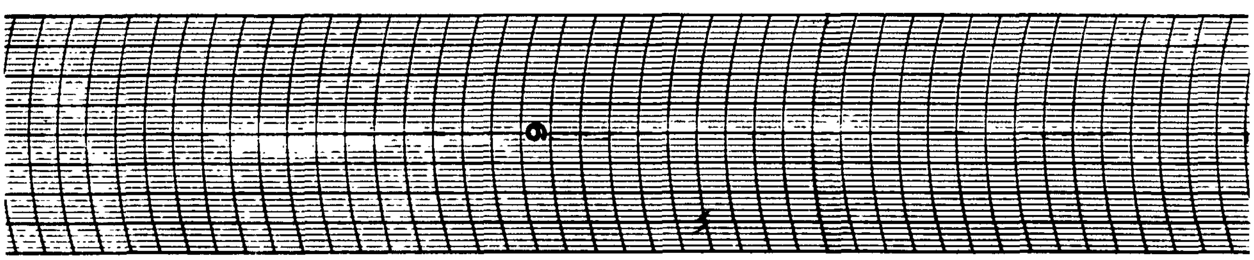


FIG. 7 (b)
GLIDE PATH RESPONSE – CONVENTIONAL AUTOPILOT
RANGE = 1000 FT.
B-25
$\mu_e = 125$



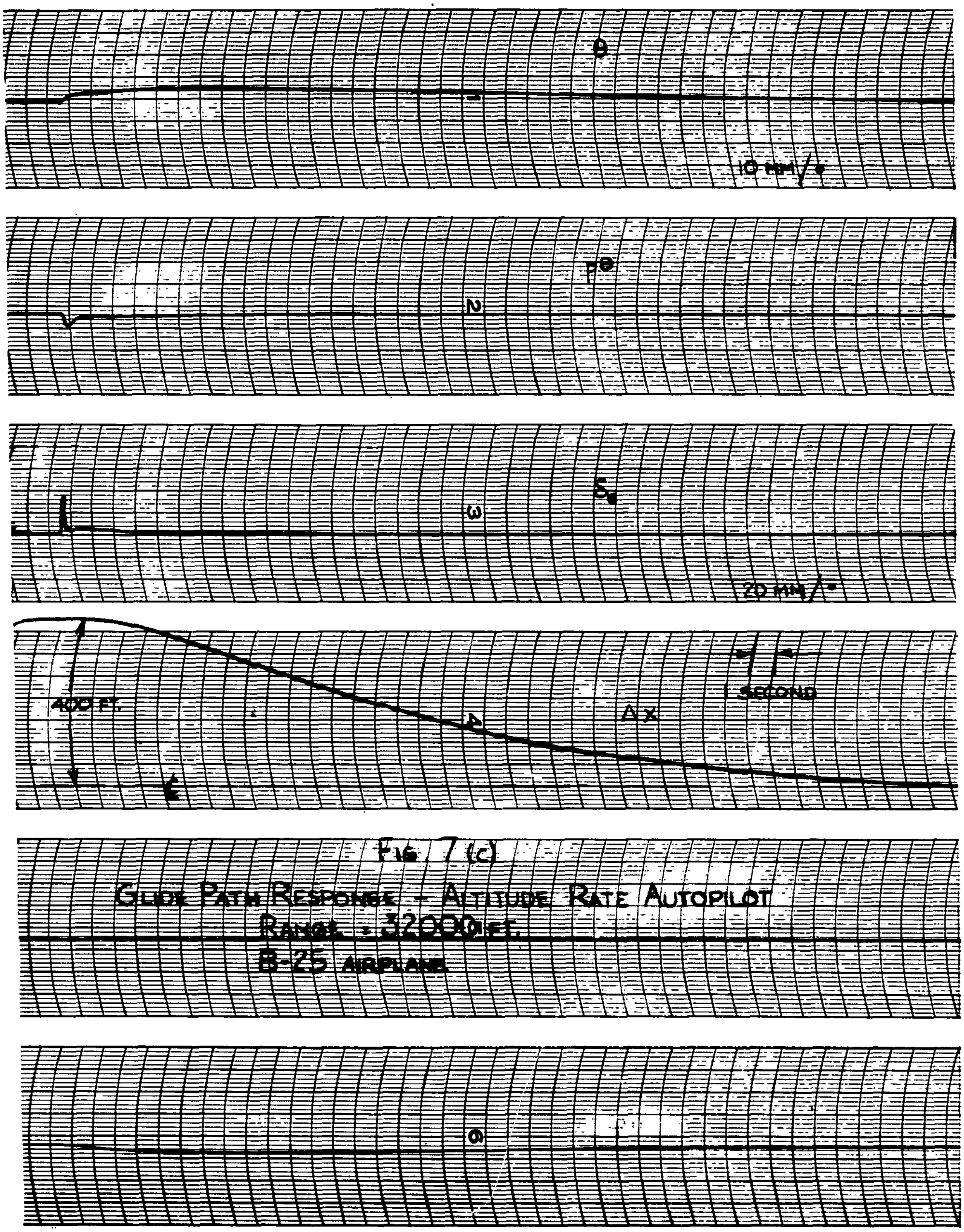


FIG. 7 (c)
GLIDE PATH RESPONSE - ALTITUDE RATE AUTOPILOT
RANGE - 32000 FT.
B-25 AIRPLANE

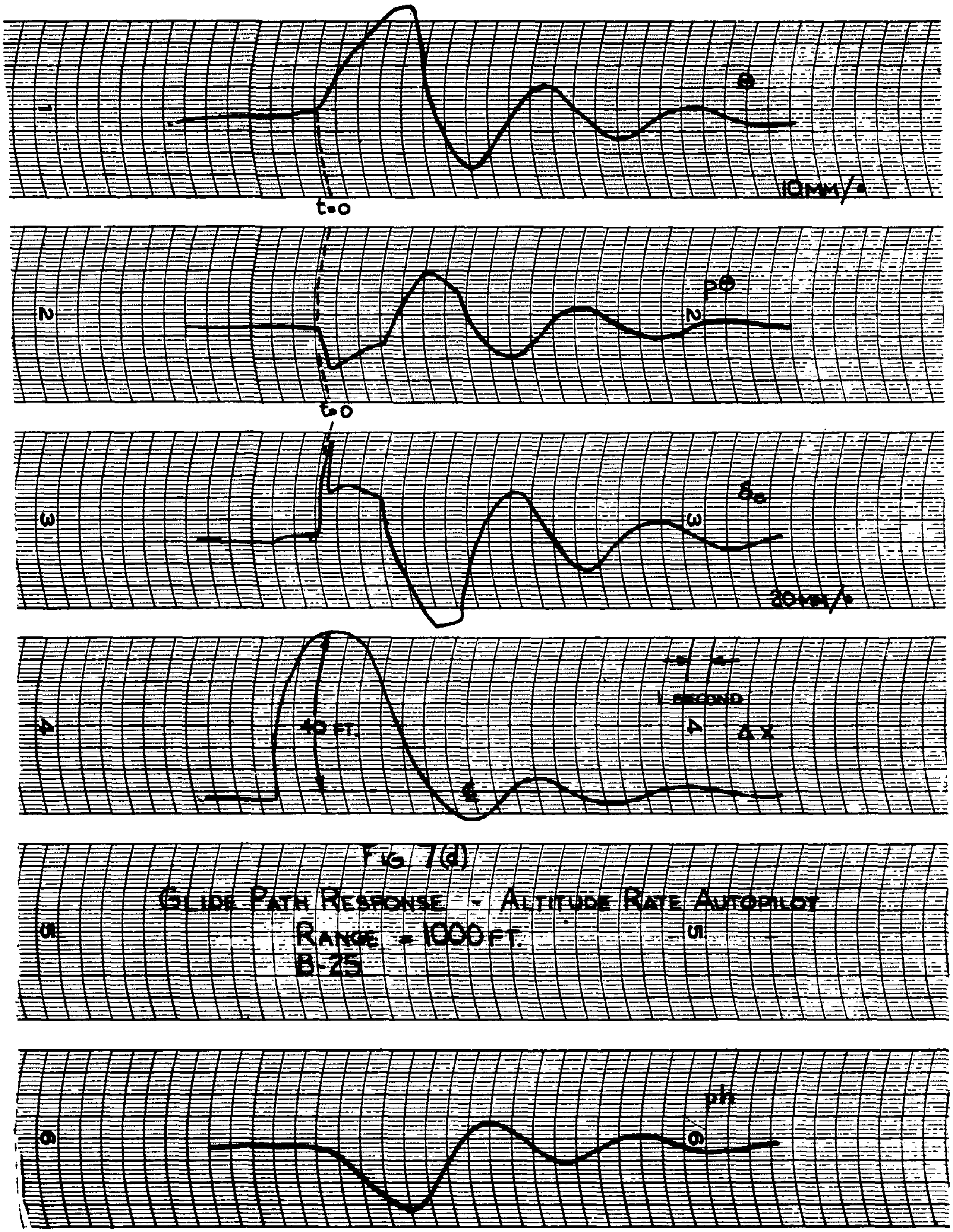


FIG. 7(d)
GLIDE PATH RESPONSE - ALTITUDE RATE AUTOPILOT
RANGE = 1000 FT.
B-25

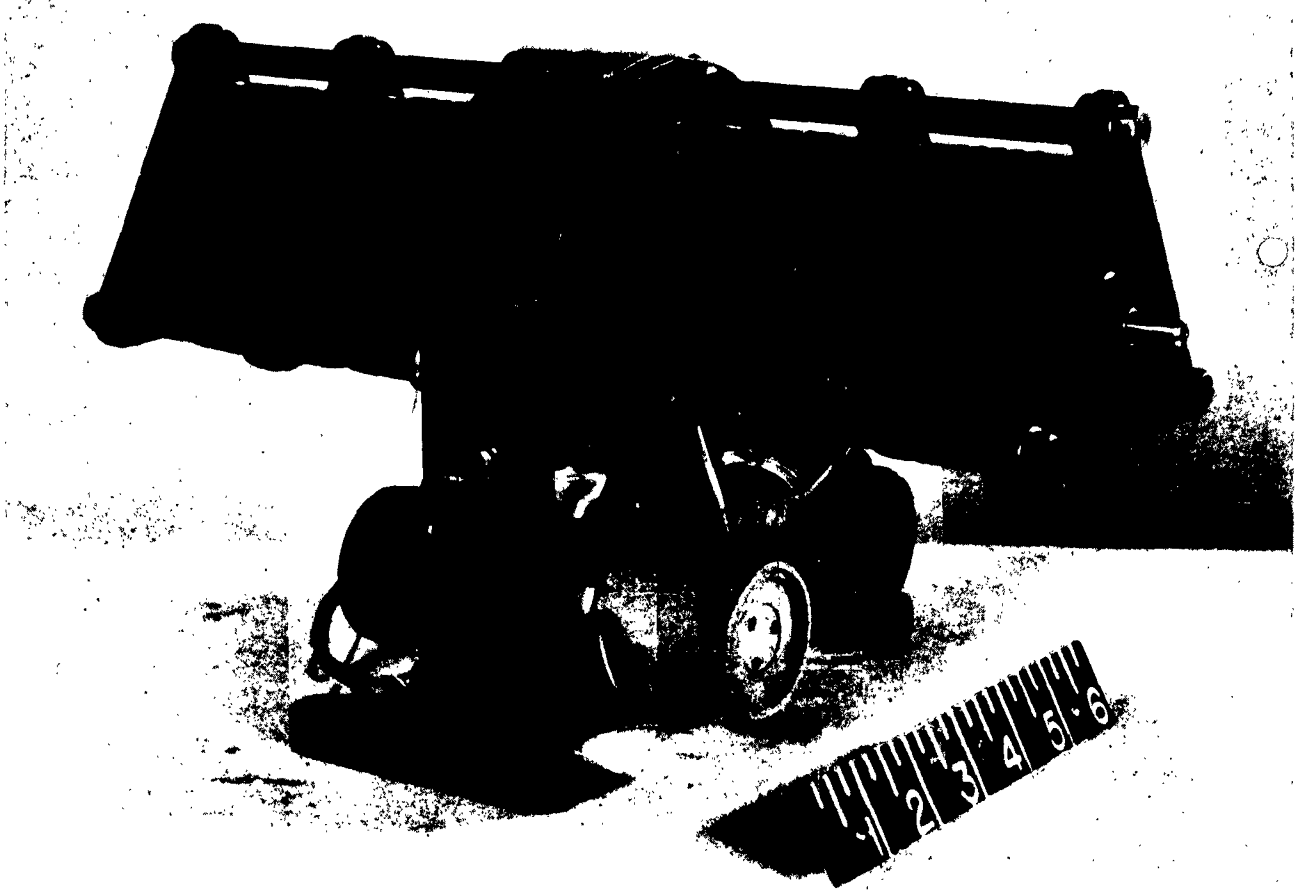
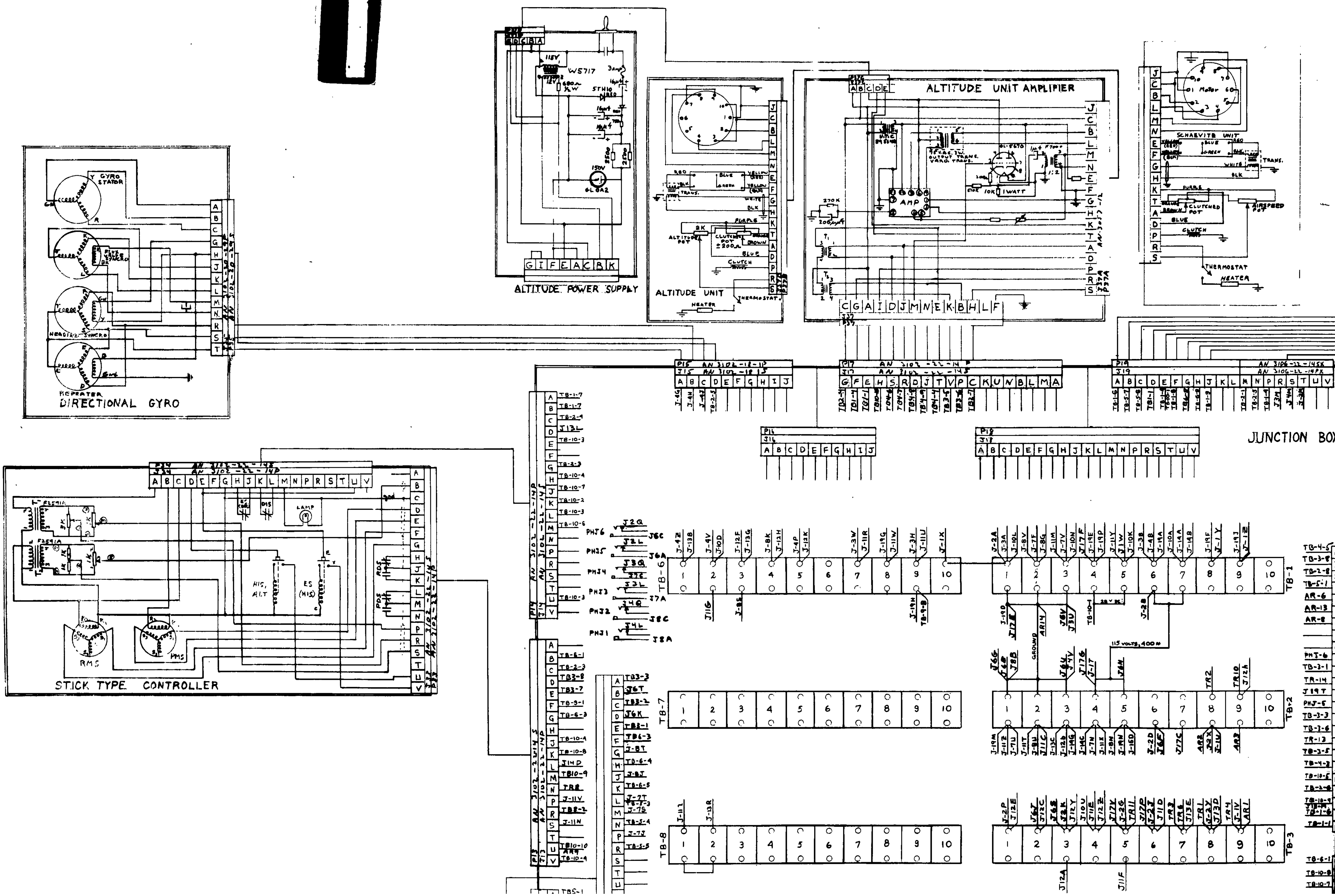


Figure 8. Bomber Throttle Servo

1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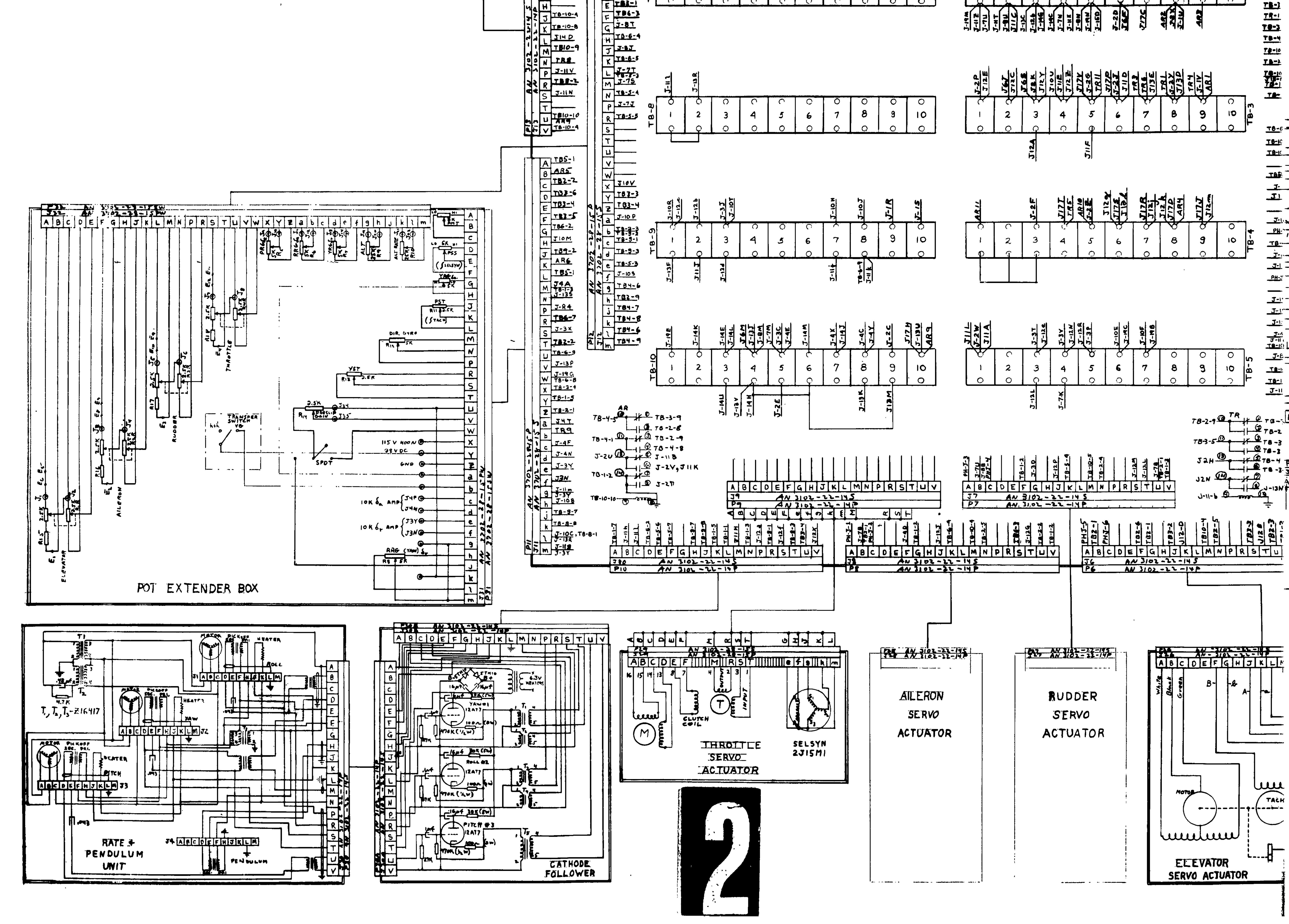
GYRO STATOR
REPEATER
HEADING SYNCRO
ALTITUDE POWER SUPPLY
WS717
6L0A2
ALTITUDE UNIT
HEATER
THERMOSTAT
ALTITUDE POT
CLUTCH
ALTITUDE UNIT AMPLIFIER
AMP
SCHAEVITZ UNIT
MOTOR
TRANS.
CLUTCHED POT
AIRSPEED POT
JUNCTION BOX
STICK TYPE CONTROLLER
RMS
PMS
LAMP
HIS, ALT
ES (HIS)
RDS
PDS
TB-1
TB-2
TB-3
TB-6
TB-7
TB-8
115 VOLTS, 400~
GROUND


POT EXTENDER BOX
RATE & PENDULUM UNIT
CATHODE FOLLOWER
THROTTLE SERVO ACTUATOR
SELSYN 2J15M1
AILERON SERVO ACTUATOR
RUDDER SERVO ACTUATOR
ELEVATOR SERVO ACTUATOR
TB-3
TB-4
TB-5
TB-8
TB-9
TB-10
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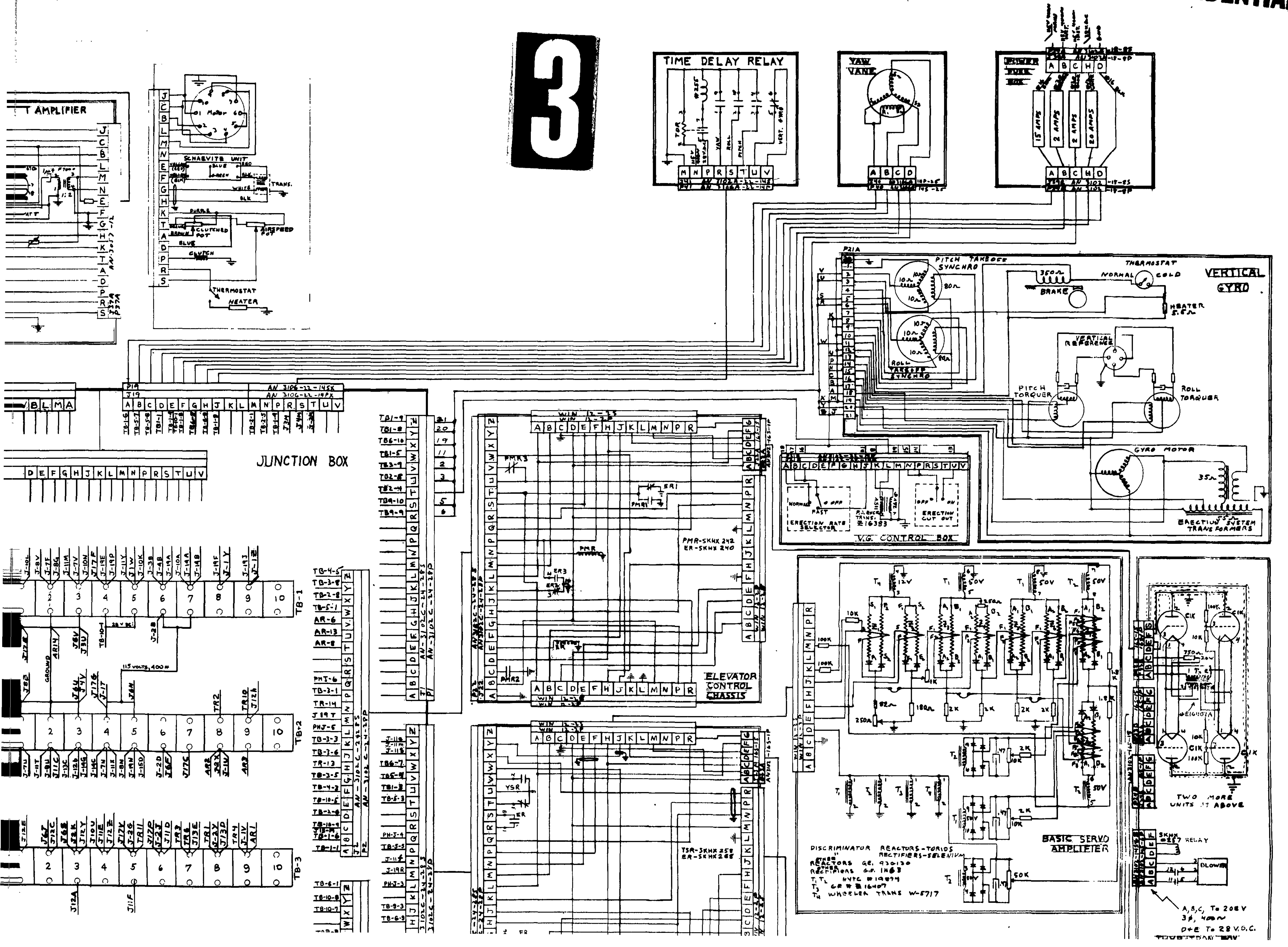
3
TIME DELAY RELAY
YAW VANE
POWER FUSE BOX
15 AMPS
2 AMPS
2 AMPS
20 AMPS
T AMPLIFIER
SCHAEVITZ UNIT
CLUTCHED POT
AIRSPEED POT
CLUTCH
THERMOSTAT
HEATER
JUNCTION BOX
TB-1
TB-2
TB-3
115 VOLTS, 400 ~
GROUND
P21A
PITCH TAKEOFF SYNCHRO
ROLL TAKEOFF SYNCHRO
THERMOSTAT
NORMAL
COLD
VERTICAL GYRO
BRAKE
HEATER 5.5 Ω
VERTICAL REFERENCE
PITCH TORQUER
ROLL TORQUER
GYRO MOTOR
ERECTION SYSTEM TRANSFORMERS
ERECTION RATE SELECTOR
ERECTION CUT OUT
V.G. CONTROL BOX
ELEVATOR CONTROL CHASSIS
PMR-SKHX 242
ER-SKHX 240
TSR-SKHX 258
ER-SKHX 268
BASIC SERVO AMPLIFIER
DISCRIMINATOR REACTORS-TORIOS
RECTIFIERS-SELENIUM
TWO MORE UNITS AS ABOVE
BLOWER
A, B, C, To 208 V 3 φ, 400 ~
D+E To 28 V.D.C.

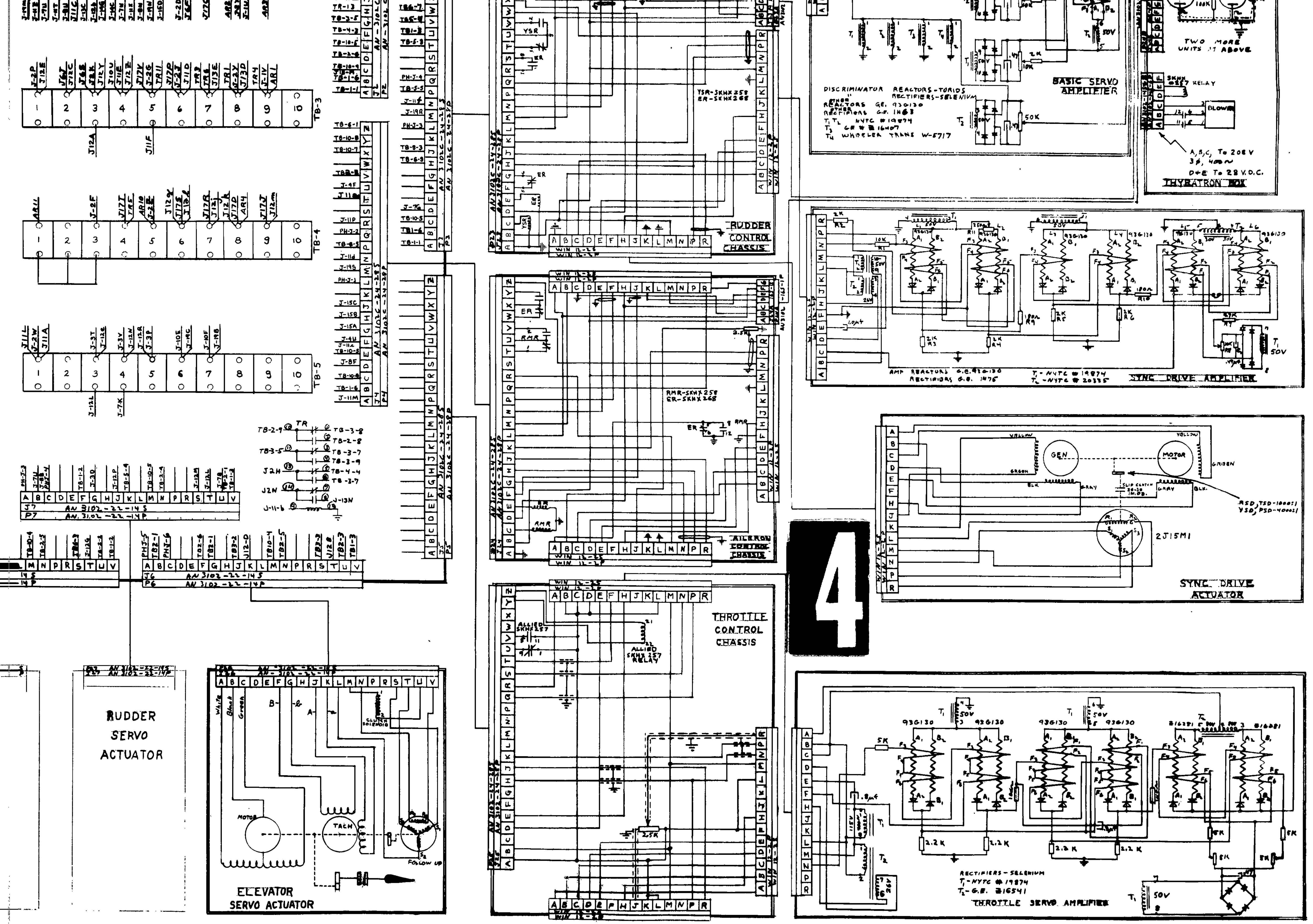

Figure 9. Fighter Autopilot System Schematic